THE CASSINI / HUYGENS MISSION TO SATURN

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Abstract

The Cassini/Huygens mission is an international cooperative effort between NASA, the European Space Agency, and the Italian Space Agency to conduct a scientific investigation of the Saturnian system. The spacecraft, which was launched in October of 1997, is using a Venus-Venus-Earth-Jupiter gravity assisted trajectory to arrive at Saturn in July of 2004. The spacecraft, composed of an orbiter and an atmospheric entry probe, will be placed in orbit about Saturn, after which the Huygens probe will be released to enter the atmosphere of Titan, the largest moon of Saturn. The probe data are transmitted during its descent and possible operation on the surface to the orbiter overhead, where it is stored and later relayed to Earth. The orbiter then continues in a four-year mission about Saturn, conducting detailed studies of the atmosphere, the rings, the magnetosphere, Titan, and the icy satellites. The probe carries six instruments to explore the atmosphere and surface of Titan; the orbiter carries twelve instruments for its investigations.

This paper characterizes the performance of the Cassini/Huygens spacecraft during its first two years of flight, up through the Earth flyby. The flight system, including the 18 scientific instruments, is described, as well as the detailed overall objectives of the mission.

Introduction

The Cassini/Huygens Project is a joint effort between the United States' National Aeronautics and Space Administration (NASA), Europe's European Space Agency (ESA), and the Italian Space Agency (ASI) to conduct a detailed investigation of the Saturnian system. The flight spacecraft consists of an orbiter vehicle which carries twelve different science instruments, as well as an atmospheric probe, which in turn carries six instruments of its own. The probe, which is provided by ESA, is carried into orbit about Saturn by the orbiter craft, and is nominally planned to be released near the end of the first 150 day orbit targeted to Titan. Total duration of the probe mission will be approximately three hours, including both the time of descent, and some expected time of operation on the surface of Titan. During these three hours, data from the probe are radioed to the orbiter passing overhead, where they are stored for later transmission to Earth. The orbiter's mission at Saturn lasts for four years, starting with Saturn orbit insertion on July 1, 2004. During this time, the orbiter will complete 75 orbits of Saturn that include 44 close, targeted encounters with Titan, 7 encounters with the smaller, icy satellites at altitudes of less than 1000 km, and an additional 27 encounters at altitudes between 1000 km and 100,000 km. Scientific investigation goals for the orbiter are Saturn's atmosphere, rings, magnetosphere, and satellites. The science community involved with the Cassini/Huygens mission is composed of about 250 scientists split approximately equally between the United States and Europe.

Mission Description

The Cassini/Huygens spacecraft was launched on October 15, 1997, using a Titan IVB/Centaur launch vehicle, onto a trajectory that would take it nearly twice around the sun and twice past Venus before an August 1999 gravity assist at Earth would at last send it out of the inner solar system, bound for Jupiter and another gravity boost in December, 2000, and finally Saturn on July 1, 2004. The combination of the 5712 kg launch weight and the high trajectory energy required to depart Earth on a direct path to Saturn far outpaced the capabilities of any launch vehicle available, and hence the need to employ the four planetary gravity assists to get such a massive spacecraft to Saturn. Figure 1 shows the path the spacecraft will follow in its lengthy and somewhat circuitous route to Saturn. Table 1 lists dates and speed changes for each of the TCMs (trajectory correction maneuver) performed to this point in Cassini's flight, as well as for each of the planetary encounters accomplished or to be done. A skipped TCM number in the sequence indicates that the opportunity for a maneuver had been planned, but that in flight, the navigational accuracy had been such that that particular maneuver became unnecessary. There are no deterministic maneuvers required from the current point in the mission (about one month after the Earth flyby) until SOI (Saturn Orbit Insertion), with the probable exception of an approximately 30 m/s maneuver about one month prior to SOI to achieve a close flyby of the Saturnian satellite Phoebe on the initial approach to Saturn. Phoebe orbits Saturn at about 215 Saturn radii, which is farther from Saturn than Cassini will ever get in the course of its orbital tour, so the approach opportunity to observe Phoebe is unique in the mission. In the absence of this maneuver, Cassini would pass Phoebe at about 56000 km. However, even though no deterministic maneuvers are required to get to Saturn, it is very likely that some small navigational corrections, perhaps three or four, will be needed to achieve the necessary flyby point at Jupiter, accommodate the normally occurring navigation dispersions at the Jupiter flyby, and achieve the final approach conditions at Saturn that will lead to the proper initial conditions in the tour after SOI.

Mission Event Summary				
Event	Location	Date	Delta - V, m/s	Earth Swingby Altitude*, km
Venus 1	Launch + 193 d	26-Apr-98	7055	24,220,565
DSM	Venus 1 + 284 d	3-Dec-98	450	42,970,946
TCM 6	Venus 2 - 140 d	4-Feb-99	11.6	2,064,333
TCM 7	Venus 2 - 37 d	18-May-99	0.24	133,955
Venus 2	Earth - 55 d	26-Jun-99	6690	133,955
TCM 9	Earth - 43 d	6-Jul-99	43.5	51,540
TCM 10	Earth - 30 d	19-Jul-99	5.1	49,651
TCM 11	Earth - 15 d	2-Aug-99	36.3	4,652
TCM 12	Earth - 6.5 d	11-Aug-99	12.2	1,172
Earth		18-Aug-99	5477	1,172
TCM 13	Earth + 13 d	31-Aug-99	6.7	
Jupiter	Earth + 500 d	30-Dec-00	2218	
Saturn (SOI)	Earth + 1779 d	1-Jul-04	623	
	* Estimated by Orbit Determination after maneuver.			

Table 1: Mission Event Summary

Figures 2 through 5 show the trajectory geometry for each of the planetary flybys that occur in the course of Cassini's transit from launch to Saturn. The left panel shows the planet relative flight path and how the gravitationally induced bending of the path was used to achieve the new post-encounter sun relative velocity. In each case, the planet relative approach and departure velocity vectors are depicted parallel to the corresponding velocity vectors in the diagram, thus indicating the actual delta-V achieved by the encounter, as well as how the direction-only change relative to the planet produces both a direction and magnitude change relative to the sun. The process by which a planetary flyby increases the sun-relative energy of the spacecraft is evident in each of figures 2 through 5. Specifically, for the first Venus flyby shown in figure 2, Cassini approaches Venus from a direction within 20 deg of being perpendicular to the motion of Venus around the sun. Since the speed of Cassini at any point in the vicinity of the flyby can be determined from the vector sum of Venus' velocity relative to the sun and Cassini's velocity relative to Venus, the relative orientation of these two vectors is critical in determining the final energy after the encounter. Depending on the magnitude and direction of the bending of the flight path during the encounter, the resulting sun relative speed can range anywhere from the arithmetic sum of the two vector magnitudes to their arithmetic difference. In the case of the first Venus encounter, it can be seen in figure 2 that the path of Cassini was rotated over 70 deg to make it essentially collinear with Venus' motion, and hence the arithmetic sum of the magnitudes, the maximum possible energy gain, was achieved.

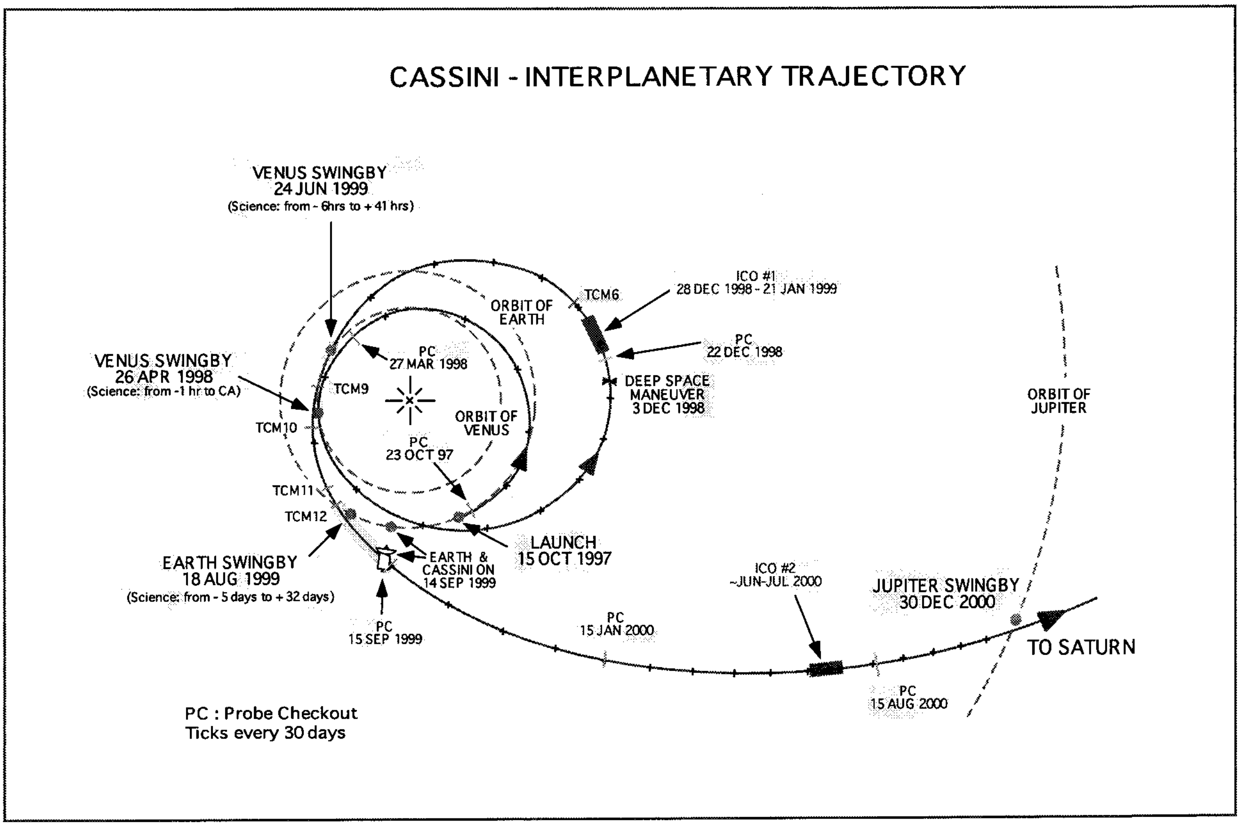

Figure 1: Cassini Interplanetary Trajectory

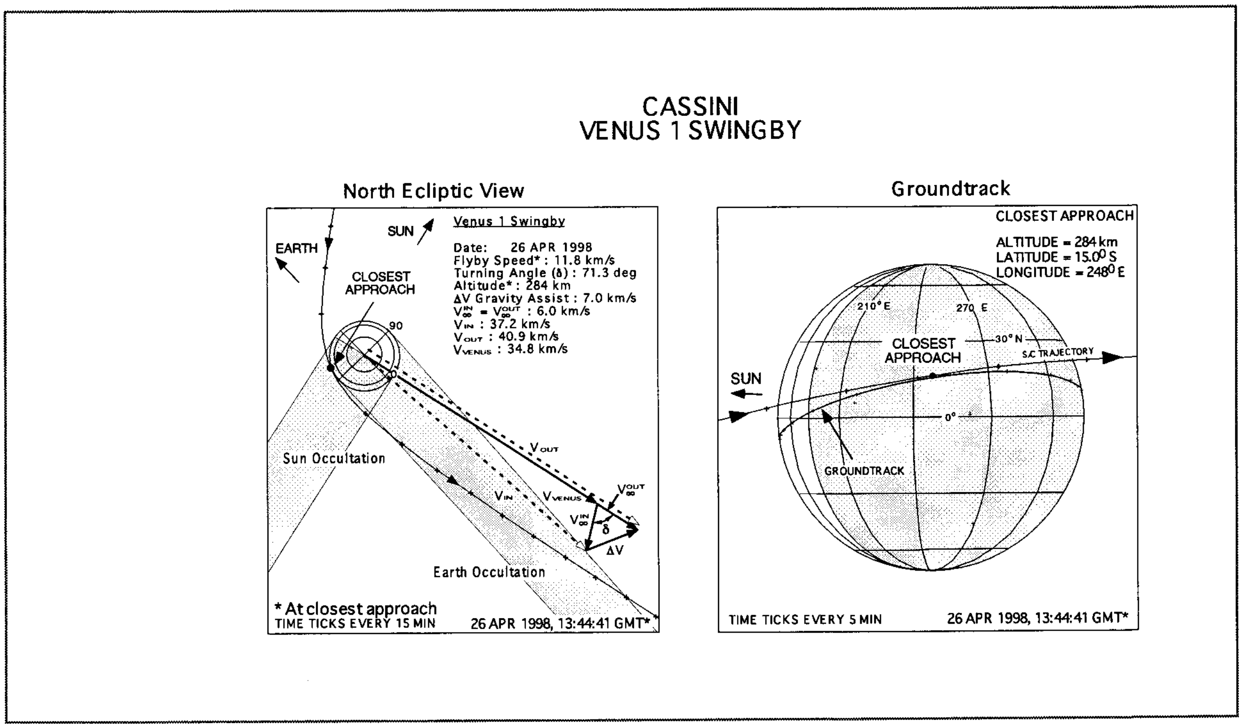

Figure 2: Cassini Venus 1 Swingby

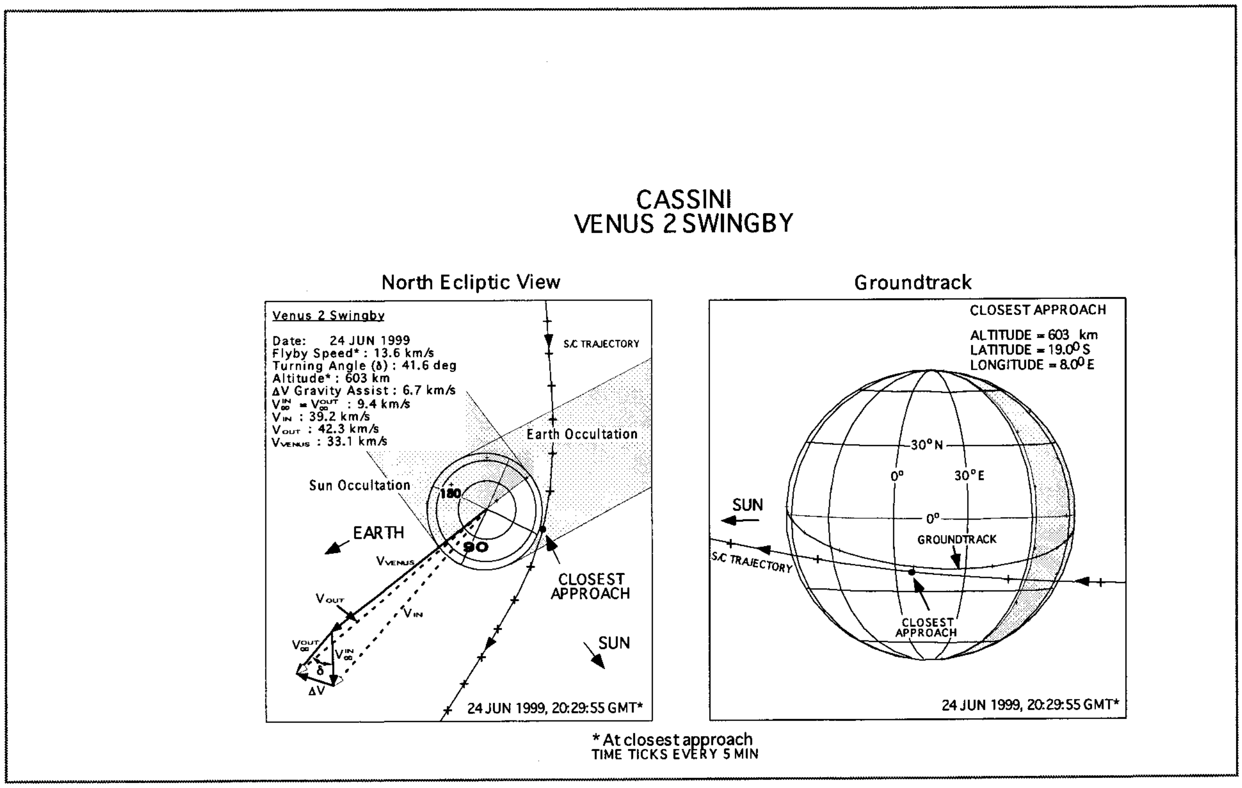

Figure 3: Venus 2 Swingby

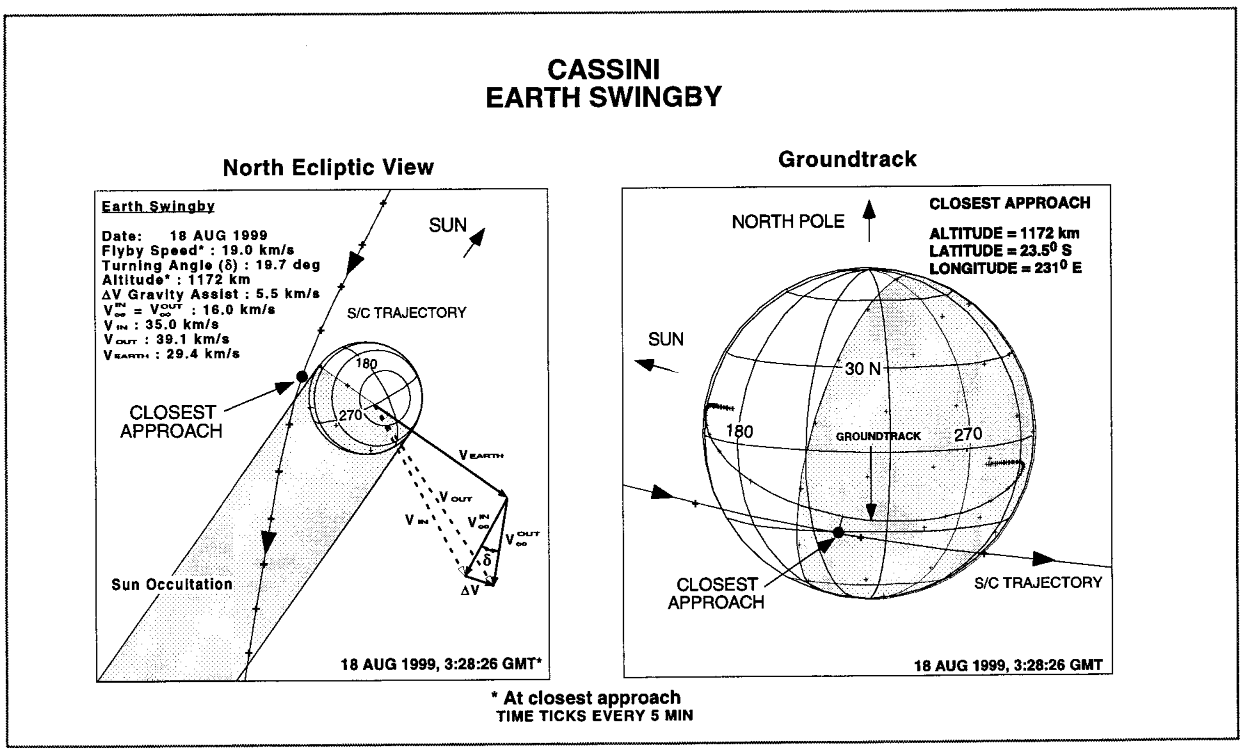

Figure 4: Cassini Earth Swingby

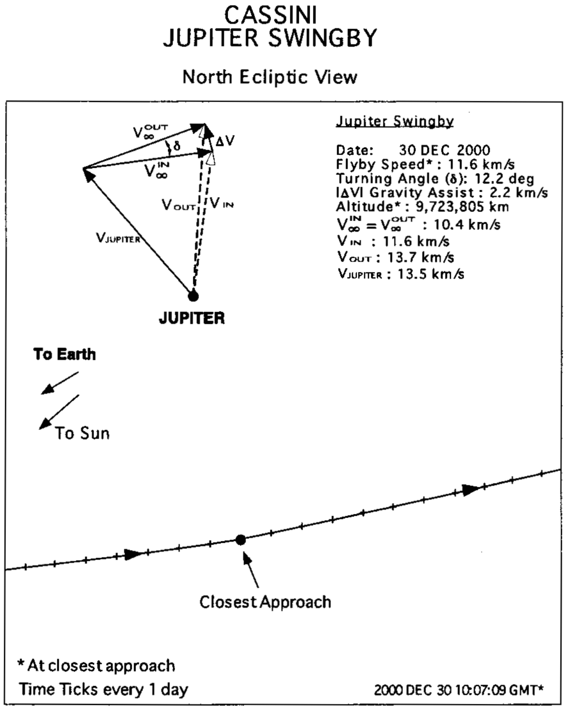

Figure 5: Cassini Jupiter Swingby

One consequence of this is that if Cassini were allowed to continue on a ballistic path around the sun to the point where it would next encounter Venus' orbit (ignoring for the moment the issue of timing and where Venus would be), Cassini would necessarily approach tangentially to Venus's orbit, and no further bending to increase energy would be possible. Only energy reductions could be achieved, and hence the need for the DSM (Deep Space Maneuver) that was performed in December, 1998, as identified in Table 1. The function of the DSM was to perform a 450 m/s retro burn at aphelion that would depress perihelion and allow Cassini to cross Venus' orbit at a non-zero path angle. The bending achieved by the encounter then achieved (at least nearly) a zero path angle again, and a sun-relative speed boost of 3.1 km/s was achieved, in addition to the sun-relative direction change necessary to reach Earth for another gravity boost, a very good return on the investment of 450 m/s of propellant at the DSM!

The listing of Earth flyby altitudes shown in Table 1 indicates where Cassini would have flown past Earth if no further active control had been accomplished from that point onward in the mission. Prior to the DSM, the very large altitudes are the result of the DSM not having been accomplished, and therefore no second Venus flyby in the trajectory. After the DSM and TCM-6, the large miss distances are the result of the normally occurring execution dispersions associated with the implementation of any maneuver, then amplified by the flyby of Venus. Starting with TCM-7, the range of flyby altitudes is the result of a pre-planned trajectory biasing strategy that was employed to ensure that Cassini would not impact Earth. If at any time prior to the Earth flyby, due to any failure on the spacecraft, the ability to navigate the spacecraft were lost, Cassini would be on a path that would carry it safely past Earth at a considerable distance. The decreasing altitude with time reflects the decreasing sensitivity to perturbations along the flight path, and hence the lesser altitudes to assure the same degree of safety, eventually leading to the final flyby at 1172 km. The targeted altitude at the last TCM 6.5 days earlier was 1166 km.

The Cassini spacecraft has had both quiescent periods as well as periods of high activity since its launch nearly two years ago. During the first Venus flyby in April, 1998, four of the science instruments were exercised. In December '98 and January, '99, a near alignment of Cassini, Earth and the sun allowed the high-gain antenna to be turned away from its normal sun-pointed attitude for thermal control reasons, and with a very small turn be pointed to Earth, thus permitting high rate telemetry to be obtained. This opportunity was used to turn on all of the orbiter instruments, many for the first time since launch, and verify their health and operation. The checkout was completed on a rather compressed timeline, due to the short-lived geometry that permitted the necessary telemetry rates, but nevertheless was very valuable both in confirming the operating status of the instruments as well as providing useful experience in operating the overall system for the first time since launch. The next high activity period occurred at the second Venus flyby, where 8 of the 12 orbiter instruments were turned on and data collected, data that served primarily as a source of calibration for the instruments, but also was of scientific value as well. The Earth encounter in August also represented a high activity period, when 9 of the instruments were used to acquire data. Data gathering activities were constrained at both encounters due to the fact that the spacecraft is designed to operate at Saturn distances from the sun, and allowable orientations at Venus and Earth distances from the sun were severely constrained to maintain thermal limitations. At Earth, the flyby geometry permitted images to be taken of the moon with only a roll turn, but none were able to be taken of Earth. Again, the activity was highly successful and data taken in such a well known environment will be very helpful in accomplishing instrument calibration. The unique and sophisticated complement of instrumentation on the Cassini spacecraft, combined with the range of Earth distances over which they operated, both near and far, also led to new science data to be collected, mostly in the area of magnetospheric physics.

A number of significant activities is planned throughout the cruise period from the recent Earth flyby to the time of arrival at Saturn, primarily to support the capability to operate the spacecraft efficiently once it has begun the orbital tour at Saturn. In February of '00, the combination of the increased range from the sun, and the ever decreasing maximum angle between Earth and the sun will allow Cassini to go to permanent pointing of the high-gain antenna to Earth. Shortly following this, new flight software for both the CDS (Command and Data Subsystem), and the AACS (Attitude and Articulation Control Subsystem) will be sent to the spacecraft. By design, the period of long cruise to Saturn is being used to develop several flight and ground capabilities that are not necessary during the interplanetary phase, but will be essential during the prime mission period at Saturn. The new flight software will be exercised extensively when Cassini/Huygens flies past Jupiter, primarily for the purpose of exercising the entire system on a fairly well known target, and in a configuration very similar to what it will be at Saturn. A second flight software upload is scheduled in the spring of '01 that incorporates some additional features needed at Saturn, as well as correcting any problems that may be uncovered in the meantime. A secondary objective at Jupiter is to do some actual scientific investigations using the more advanced instrumentation capability than was available on either Voyager or Galileo. In addition, it is hoped to perform a joint and simultaneous investigation of Jupiter's magnetosphere with Galileo, with Galileo making measurements deep in the magnetosphere while Cassini makes simultaneous measurements outside of and just inside of the magnetosphere. This would be the first time any such experiment would have been performed, and should provide the capability to understand how the solar wind interacts with and influences the different parts of the magnetosphere. The one lien on this plan is that Galileo will by then have completed three years of its extended mission, a total of five years at Jupiter, and will have accumulated a radiation dose well beyond its design limit, so there is no assurance that it will still be operating well enough to support such an investigation.

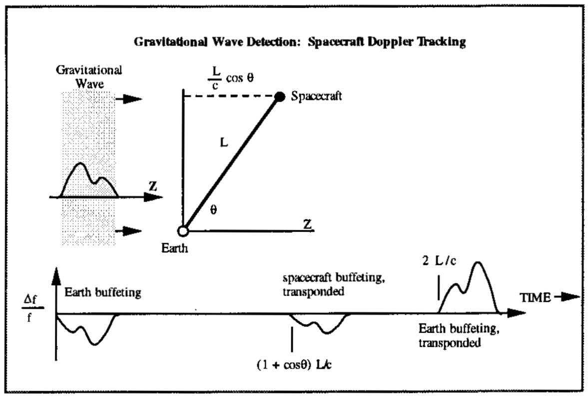

Figure 6: Gravitational Wave Detection: Spacecraft Doppler Tracking

Another scientific investigation that Cassini will conduct during the cruise phase between Jupiter and Saturn is the search for gravitational waves using spacecraft Doppler data. This is one of the proposed and approved investigations when the Cassini Program was initially approved and the investigation complement was selected. NASA is currently developing the capability to transmit a Ka-band (~ 32 GHz) signal from Deep Space Station 25 of the Deep Space Network at Goldstone, CA, which Cassini will receive and transpond back to Earth. The most accurate experiment of this type done to date was with the Mars Observer spacecraft using X-band (~8 GHz) Doppler, and no gravitational waves were discovered. Cassini, using the Ka-band frequency, will achieve an increased sensitivity by more than one order of magnitude better than was possible with X-band Doppler. The basis of this experiment is indicated in figure 6. The gravitational wave, propagating from left to right in this example, first buffets Earth, causing an immediate change in the Doppler signal seen at the tracking station. The second effect to be seen is when the signal from the buffeted spacecraft is received at the station, and finally, one round-trip Earth to spacecraft lighttime later, the final effect is seen when the effect of the initial buffeting of Earth is retransmitted from the spacecraft and received at Earth. The experiment is planned to be conducted three times between Jupiter and Saturn during periods of solar opposition in order to minimize the background solar induced noise.

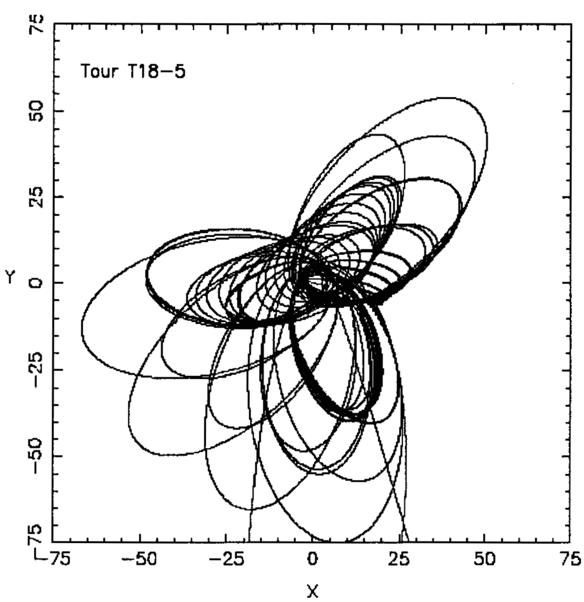

Figure 7: Saturn Tour: Pole View

The science data gathering plans during the four year orbital tour at Saturn are very ambitious. The Program has selected the tour to be flown from the rather large set of candidate tours that was generated based on the opportunities it provided for science data collection, as well as on considerations of the demands such a tour would place on the ground system. The selected tour, identified as T18-5, will complete 75 orbits in the course of the four year orbital prime mission. These orbits contain 44 close targeted flybys of Titan, 28 of which are at altitudes less than 1300 km, seven flybys of various of the smaller, icy satellites at altitudes of less than 1000 km and 27 additional at ranges up to 100,000 km, and numerous opportunities for occultations of Earth by Titan, Saturn, and its rings. Figure 7 shows a Saturn north pole view of the trajectory to be flown. The region of near Saturn space covered is quite extensive, providing an excellent opportunity for fields and particles measurements throughout the Saturnian system. Figure 8 shows a view of the tour from in the Saturn equatorial plane, and indicates the three dimensional nature of the covered region. The inclination over the course of the tour ranges from equatorial to about 75 deg.

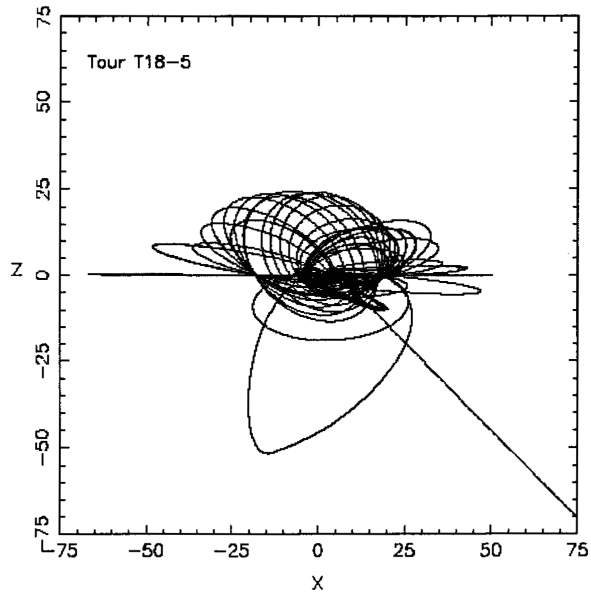

Figure 8: Saturn Tour: Equatorial View

Since the Cassini spacecraft does not have an articulatable platform, it is necessary to turn the entire spacecraft to achieve the various pointing orientations required by the instruments. Spacecraft turns can be performed using either the hydrazine thrusters or the Reaction Wheel Assemblies (RWA). The operational plan to accommodate this feature is to spend about 16 hours of each day collecting data, storing it on the spacecraft's solid state recorders of approximately 4 Gbit capacity, and then for 8 hours of each day, turn the HGA to Earth and play back the acquired data. The remote sensing instruments won't be able to operate during the playback period, but it is expected that the fields and particles instruments will, since they are considerably less affected by the constrained spacecraft attitude. The limitation on total data volume to be returned will most likely be determined by the total time allocated to downlink, and the available data rates, rather than data storage capacity on the spacecraft.

The Huygens probe is carried into orbit with the orbiter at Saturn, and then released, targeted to Titan, on November 6, 2004, near the end of the first orbit about Saturn, and shortly prior to the first Saturn periapsis after SOI. Huygens' entry into Titan's atmosphere occurs 21 days later, on November 27. Soon after the release of the probe, the orbiter will perform a retro/deflection maneuver to set up the proper geometry for the orbiter to receive the signal from the descending probe via an S-band link through the orbiter HGA. The geometry for the relay is configured so that the descending probe is generally out in front of the orbiter as it approaches on the asymptote of the flyby trajectory, with the three hour relay link complete about 1.5 hours before the orbiter reaches the point of closest approach to Titan. The probe descent sequence through the atmosphere is illustrated in figure 9. The descent profile through the nominal atmosphere has the probe reaching the surface in 135 minutes, with an impact speed of about 5 m/s. It is expected, although by no means assured, that the probe will survive the landing and continue to operate on the surface, which is the reason for the orbiter remaining oriented and configured to receive the probe signal for the three hour period.

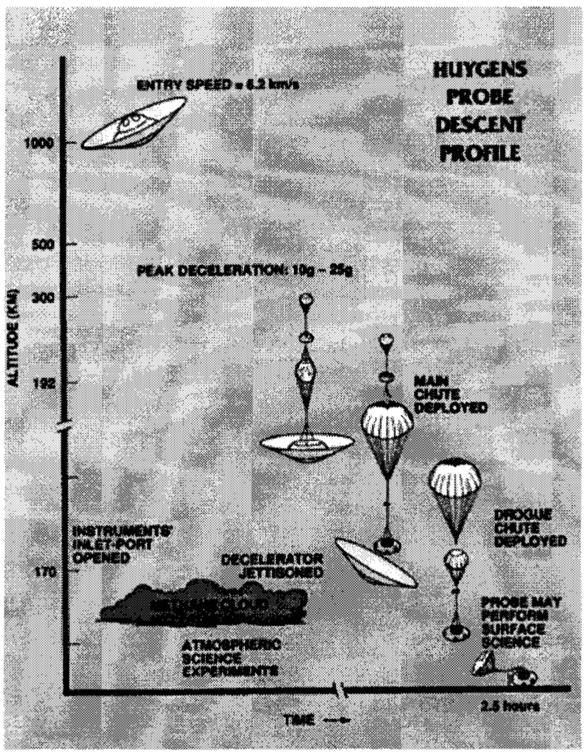

Figure 9: Huygens Probe Descent Profile

The Spacecraft

The design of the Cassini/Huygens spacecraft was driven by a large number of requirements, larger than those imposed on most interplanetary spacecraft, due largely to the route it would take to Saturn and the ambitious nature of its mission. The spacecraft had to function at solar ranges spanning from less than 0.7 AU while near Venus, out to 10 AU while at Saturn operating in its prime mission mode, all the while maintaining thermal control, attitude control, telecommunications, and navigation capabilities. Three large deterministic maneuvers along its path, the DSM, orbit insertion at Saturn, and periapsis raise near apoapsis of the first orbit, along with numerous navigational maneuvers, drove a propulsion subsystem design whose 3132 kg propellant load at launch was slightly more than half of the total launch mass of 5712 kg. Figure 10 shows a drawing of the spacecraft in its flight configuration, minus the blanketing that provides thermal control and micrometeoriod protection, and which covers most of the detail available in the figure. Key subsystems are identified. Figure 11 shows a photograph of the spacecraft, taken from the side where the Huygens probe is mounted, as it sat in the Solar-Thermal-Vacuum chamber awaiting environmental testing. An indication of the size of the flight unit can be obtained by noting the four people working around the base of the spacecraft.

The Cassini/Huygens spacecraft carries some subsystems that are of tried and proven vintage, as well as several new technologies developed specifically for Cassini, but now available to be adapted by other missions, and many already have. For electrical power, Cassini carries three RTGs (radioisotope thermoelectric generator) somewhat similar in design to those used on the Voyager spacecraft now over 20 years ago, and the same as those used more recently on the Galileo and Ulysses spacecraft. These devices have proven extremely reliable, have no moving parts, and are essential for exploration in the outer solar system. The power demand made by Cassini's engineering subsystems and scientific instruments required that three RTGs be flown, producing around 885 watts of electrical power at launch and about 630 by the end of the mission in 2008. The propulsion subsystem, although designed unique to Cassini's specific requirements, is the standard bipropellant, helium pressurized system that other spacecraft have utilized. The telecommunications system uses one high-gain antenna and two low-gain antennas. The HGA is to be used primarily for high-rate communications during the tour phase of the mission. LGA-1 is mounted collinear with the HGA boresight and is used for communications when solar ranges don't permit using the HGA, but when Earth is in the forward hemisphere of the spacecraft. The second LGA is mounted to the side of the spacecraft, and was used during those portions of the orbit when Cassini was inside of Earth's orbit, and Earth was not visible to LGA-1. Both the HGA and LGA-1 were provided by the Italian Space Agency.

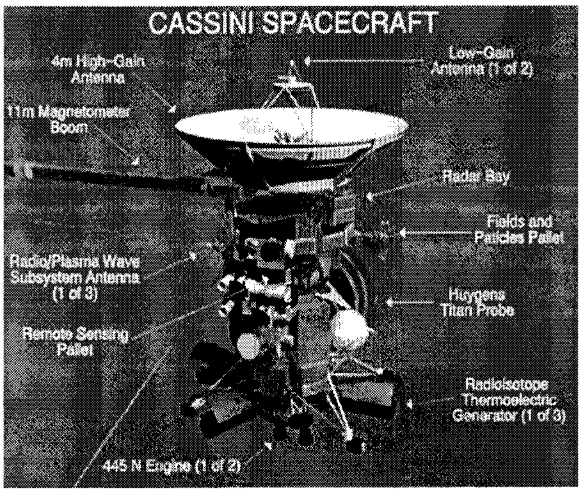

Figure 10: Cassini Spacecraft

New technologies developed by the Cassini Program include solid state recorders with no moving parts, which are now planned to be used by over 20 other missions. The spacecraft's central computer utilizes both Very High Speed Integrated Circuits and Application Specific Integrated Circuits, both developed for Cassini, which lead to high speed processing and many fewer traditional chips than would otherwise be required. All power switches on the spacecraft are solid state, which provide for long life times, as well as eliminating the electrical transients associated with traditional switches. The gyros used by Cassini for inertial attitude reference are "hemispherical resonator" gyroscopes, with no moving parts, are about the size of a dime, and use less power and have greater functional lifetimes than their mechanical counterparts. Additional details about how the legacy of Cassini has benefited many of the new small missions are available in reference 5.

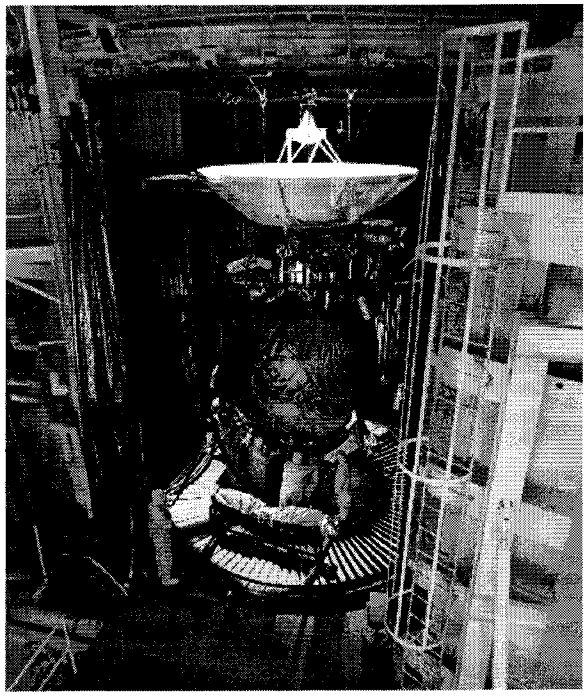

Figure 11: Cassini in Solar-THermal-Vacuum Chamber

The Payload

The Cassini/Huygens spacecraft carries a total of 18 scientific instruments, of which 12 are on the orbiter, and 6 on the probe. The full set was selected and designed to provide the widest possible range of capabilities to study the Saturn system, and at the same time to insure that the different data sets that would be collected would be complementary in their ability to understand the overall Saturnian system.

Orbiter Instruments

All of the Cassini orbiter instruments are mounted directly to the spacecraft, i.e., there is not a scan platform or spin table. The four remote sensing instruments are mounted on what is referred to as the remote sensing pallet with parallel boresights, and are pointed by turning the spacecraft. The in-situ, or fields and particles, instruments generally have less stringent pointing requirements than the remote sensing instruments. Preferred attitudes can be accommodated by turning the spacecraft when remote sensing is not active, and slow rolls about the -Z axis (HGA boresight) are planned during periods of data playback when the HGA is Earth pointed. Figure 12 shows the wavelength range across the electromagnetic spectrum covered by the remote sensing instruments, and figure 13 shows the range of particle energies covered by the fields and particles instruments.

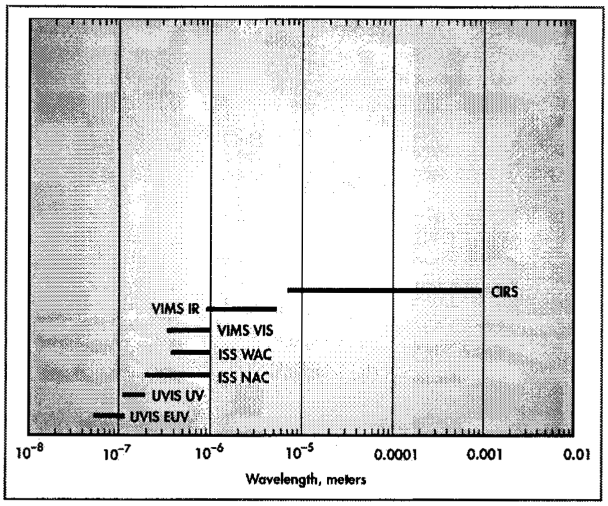

Figure 12: Wavelength Coverage Capabilities

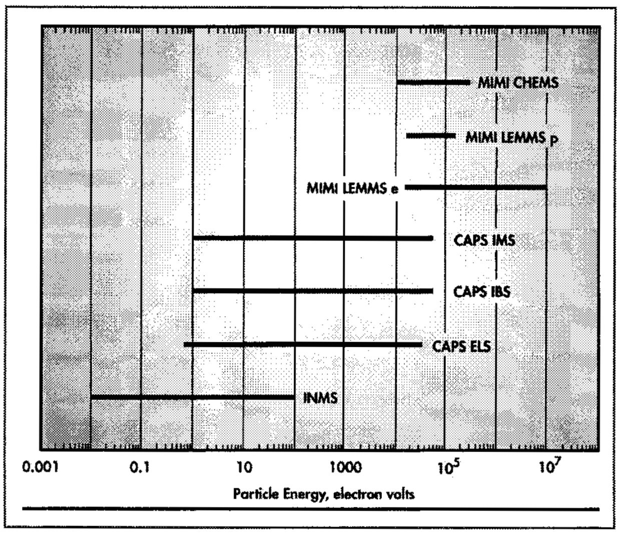

Figure 13: Particle Energy Measurement Capabilities

<u>ISS</u> The Imaging Science Subsystem consists of a narrow angle camera and a wide angle camera, with fields of view of 6 mrad and 60 mrad, respectively. The camera pair permits both very high resolution imaging as well as global coverage of targets of interest. The ISS is also used to support optical navigation by imaging the satellites of Saturn against known star backgrounds.

<u>VIMS</u> The Visible and Infrared Mapping Spectrometer consists of two imaging grating spectrometers that will map the surface spatial distribution of the mineral and chemical features of targets in the Saturn system, from which composition, temperature, and structure can be determined.

<u>CIRS</u> The Composite Infrared Spectrometer is a coordinated set of three interferometers designed to measure infrared emissions over longer wavelengths than measured by the VIMS instrument, and will determine temperature and composition profiles.
UVIS - The Ultraviolet Imaging Spectrograph is a set of detectors designed to measure ultraviolet light coming from atmospheres, rings, and surfaces to determine composition, distribution, aerosol content, and temperatures.

<u>Radar</u> The radar instrument is used primarily to investigate the surface of Titan. The four observation types of the instrument are imaging, altimetry, backscatter, and radiometry.
Radio Science - The Radio Science Investigation uses the spacecraft's radio system and the tracking stations of the Deep Space Network to study the composition, temperature, and pressure profiles of the atmospheres of Saturn and Titan, the radial structure and particle distribution of Saturn's rings, and the masses of objects in the Saturn system.

<u>CAPS</u> The Cassini Plasma Spectrometer consists of three separate spectrometer sensors that will measure the composition, density, flow velocity, and temperature of ions and electrons in Saturn's magnetosphere.

INMS The Ion and Neutral Mass Spectrometer will determine the composition and structure of positive ions and neutral particles in Titan's upper atmosphere and Saturn's magnetosphere, the positive ion and neutral environment of the icy satellites and rings, and the chemical, elemental, and isotopic composition of gaseous and volatile particle components in Titan's atmosphere, Saturn's magnetosphere, and the rings.

CDA The Cosmic Dust Analyzer will provide direct observations of small ice and dust particles in the Saturn system in order to investigate their physical, chemical, and dynamic properties and study their interactions with the rings, satellites, and magnetosphere of Saturn.

MAG The Dual Technique Magnetometer will determine the magnetic fields of the planet and satellites, and study dynamic interactions between different magnetic fields in the planetary environment.

MIMI The Magnetospheric Imaging Mass Spectrometer is designed to measure the composition, charge state and energy distribution of energetic ions and electrons, detect fast neutral particles, and conduct remote imaging of Saturn's magnetosphere. This is the first instrument ever designed to produce an image of a planetary magnetosphere.

RPWS The Radio and Plasma Wave Subsystem instrument will measure electrical and magnetic fields in the plasma of the interplanetary medium and Saturn's magnetosphere, as well as electron density and temperature.

Probe Instruments

DISR The Descent Imager/Spectral Radiometer uses 13 different sensors to obtain a variety of spectral and imaging observations, including observations of the surface during the final stages of the descent. A lamp is used shortly before landing to provide sufficient illumination to measure the surface composition.

HASI The Huygens Atmospheric Structure Instrument investigates physical and electrical properties of Titan's atmosphere, including temperature, pressure, and atmospheric density as a function of altitude. Using a variety of sensors, the HASI will also measure the ion and electron conductivities of the atmosphere, and search for electromagnetic wave activity.

ACP The Aerosol Collector and Pyrolyzer extends a sampling device into the atmosphere during descent to capture aerosol particles. These particles are heated to vaporize the volatiles and to decompose any complex organic materials. These products are then passed to the GCMS for analysis.

GCMS The Gas Chromatograph and Mass Spectrometer provides a quantitative analysis of the composition of Titan's atmosphere.

DWE The Doppler Wind Experiment uses one ultrastable oscillator on the probe and a second one on the orbiter to measure the Doppler shift from the probe to the orbiter, from which a height profile of the wind along the line-of-site can be determined.

SSP The Surface Science Package contains a number of sensors to determine the physical properties and composition of Titan's surface. Some sensors in this instrument are also designed to function during descent.

Summary

The Cassini/Huygens spacecraft has completed two years of flight since its launch on October 15, 1999, with essentially flawless performance. The science instruments have all been turned on and checked out, most of them collected science data during the second Venus flyby and the Earth flyby, and all are in excellent condition. The Huygens probe has been powered on and checked out five times since launch, and it, including all six of its science instruments, is in perfect health. The development of the flight software to be used in the Saturn tour is on schedule, with the first uplink scheduled for March, 2000, and a thorough exercising of this capability is planned during the Jupiter flyby in December, 2000. The overall prospects for an outstanding Cassini/Huygens mission at Saturn are excellent.

Acknowledgments

The work described in this paper represents the work of the entire Cassini team, including not only the current flight team at JPL, but also a large group of scientists from across the United States and Europe, as well as the engineers and supporting staff who designed, built, and launched this marvelous spacecraft. Special recognition is due to Suzän Elliott for the detailed design and layout of the paper, as well as coordination of the final printing.

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5) Faster, Better, Cheaper: An Institutional View, L. Dumas, A. Walton, IAF-99-U.2.03, October, 1999
6) Communications with John Armstrong